

COBRA High Current Generator

Baseline Design

Prepared for Cornell University

By

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Introduction

The Laboratory of Plasma Studies at Cornell University, with support from the Department of Energy, is establishing a Center of Excellence for the study of pulsed power driven high energy density plasmas. The Center will carry out experiments addressing the fundamental physics of exploding wires and multi-wire arrays in different configurations. Applications include improving the performance of wire-array z-pinch as x-ray sources, laboratory simulation of astrophysical phenomena, studies of radiation-dominated plasmas, interaction of plasma jets with target plasmas, and the atomic physics of highly stripped high-Z elements. Isentropic compression experiments at the 100 kbar level will also be carried out.

An important part of this Center is rebuilding the COBRA accelerator at Cornell so that it will be capable of delivering a 1 MA, 100 ns current pulse to a low impedance load. This document describes the baseline design for the new COBRA high current accelerator and is intended to serve as the basis for a preliminary design review.

Description of the COBRA Generator

The high current COBRA accelerator is being designed to meet the following criteria:

1. Reliably drive a Z-pinch load at 1 MA with a 100 ns, 0-peak risetime.
2. Pulsewidth adjustable to >200 ns to accommodate different experiments.
3. Load orientation along a vertical axis with the load at the top of the vacuum power feed.
4. Provide horizontal and vertical line-of-sight access to the load for diagnostics.
5. Operate at > 1 pulse/day.
6. Fit within the existing room.
7. Provide ample space around the load to accommodate both experimentalists and diagnostic equipment.

To help insure reliable operation, the baseline design was developed with the assumption that >1 MA would be achieved in a Z-pinch load with the Marx capacitors charged to 70% of their rated value, and that breakdown percentages throughout the water lines were limited to 50% under these conditions.

A variety of different configurations using one or more pulse forming lines and either gas insulated triggered spark gaps or self break water gaps for the output switches were examined. The baseline design selected consists of two, 84.4 nF, 1.1MV Marx generators, each charging a 45 nF intermediate storage capacitor (ISC). Each ISC is connected to an electrically triggered gas insulated spark gap, which in turn is connected to 2 pulse forming lines (PFL). Each 1.8 O, 30 ns PFL has its own laser triggered gas insulated output switch. Triggering the switches at different times will result in different current pulse shapes.

The 4 PFL's converge on a central adder region. This region consists of an annular water region, the vacuum interface, power feed and load. The annular water region serves as a 14 nF peaking capacitor, which makes it possible to obtain the high di/dt current pulse despite the relatively high inductance of the gas output switches. The vacuum power feed is configured so that the load is located above the height of the vacuum insulators.

The PFL's are oriented horizontally with the output switches located in oil-insulated regions that are orientated at 15 degrees from the vertical. This raises the vacuum section above the level of the pulse power. A platform will be located over the pulsed power, with the load at table-top height relative to the surface of the platform. The height of the platform will allow equipment and diagnostics to be located and easily accessed under it.

Figure 1 shows the baseline design with the platform removed for clarity. Figures 2 and 3 are section views of the generator.

The COBRA room is approximately 48' long and 21' wide. Only 16' of this width is high bay area and served by an overhead bridge crane. The baseline COBRA design will

fit within this area. Figure 4 shows the footprint of the design in room. Space is available at one end of the room to serve as a staging area.

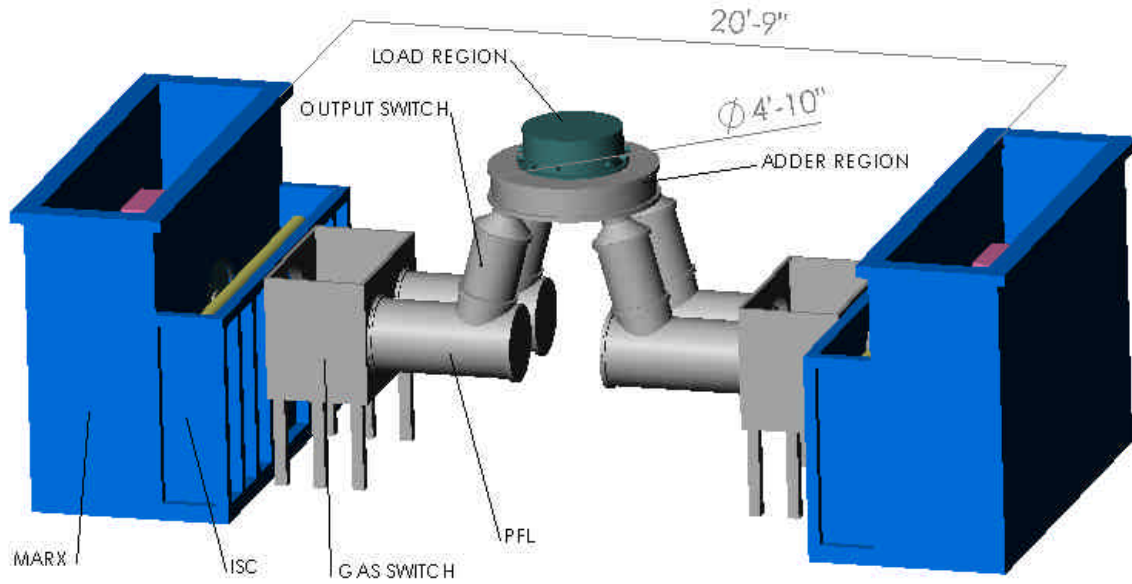


Figure 1. COBRA Baseline Design. Platform not shown.

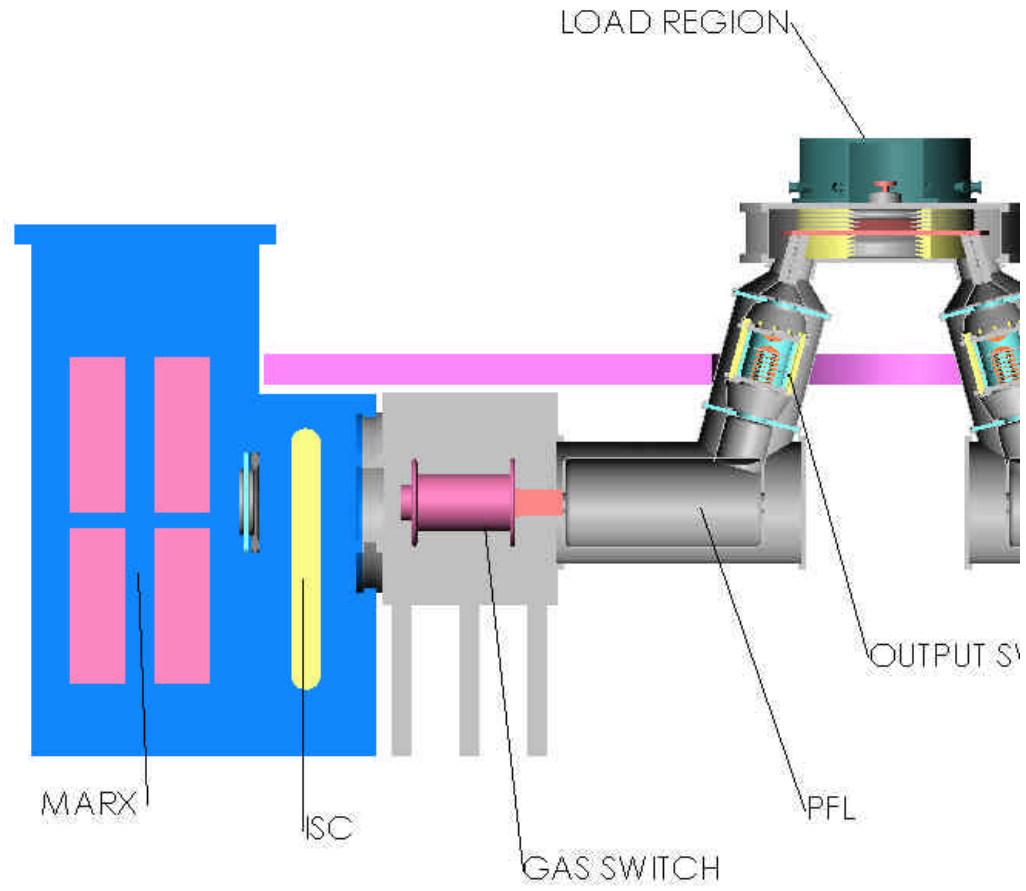


Figure 2. Section view along the center of one PFL.

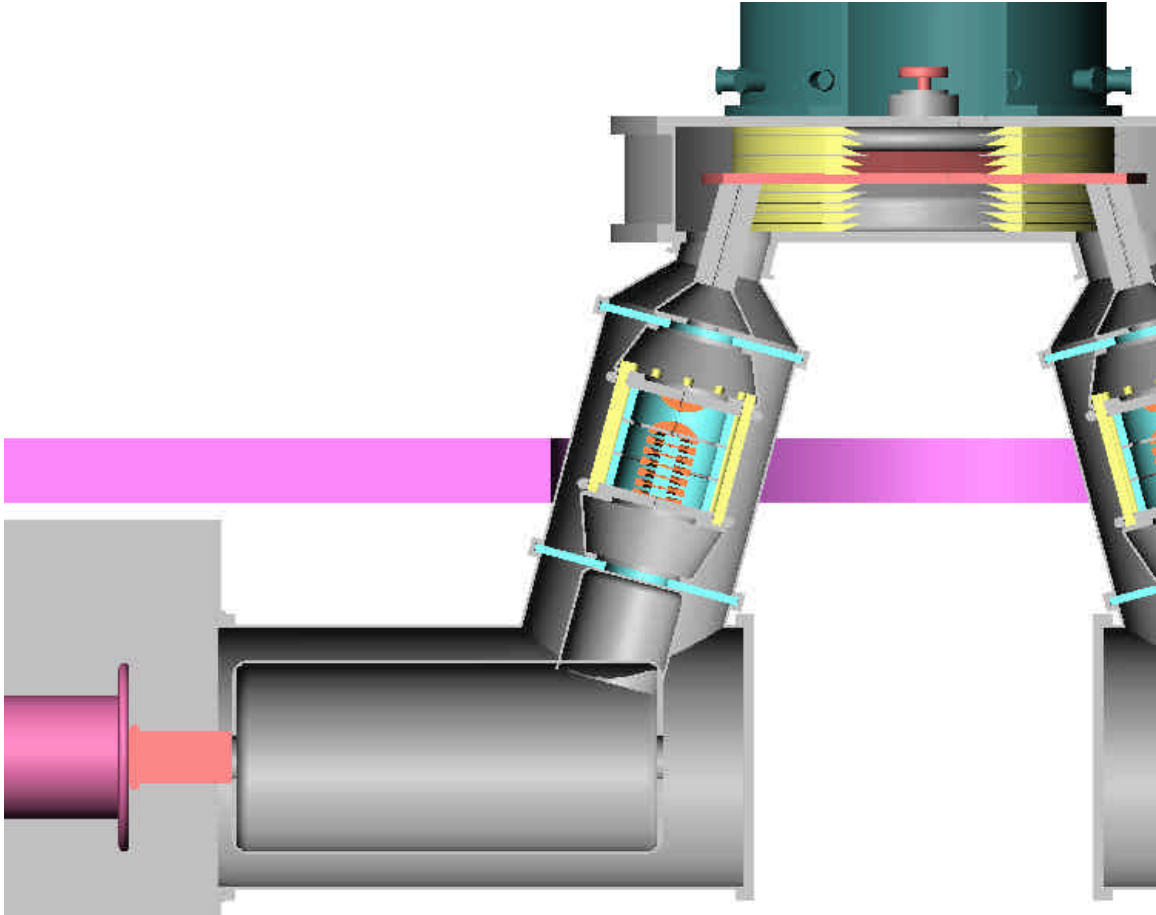


Figure 3. Close-up of section view of one PFL/output switch region.

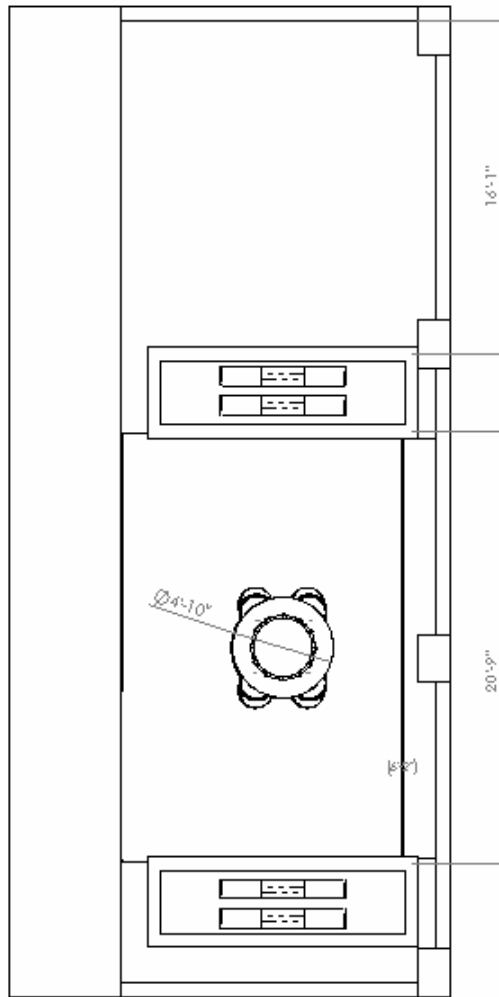


Figure 4. Layout of COBRA in existing room.

The following section will show some of the circuit simulation results. Additional details about the generator will be described in subsequent sections.

Circuit Modeling

Spice circuit modeling was used to develop the electrical parameters for the design. Figure 5 shows the Spice circuit model. Because Spice is essentially a 1-D model, it does not accurately portray the behavior at the adder region. The radially and tangentially connected array of transmission lines shown in the circuit are used in an attempt to incorporate some 2-D effects into the simulations.

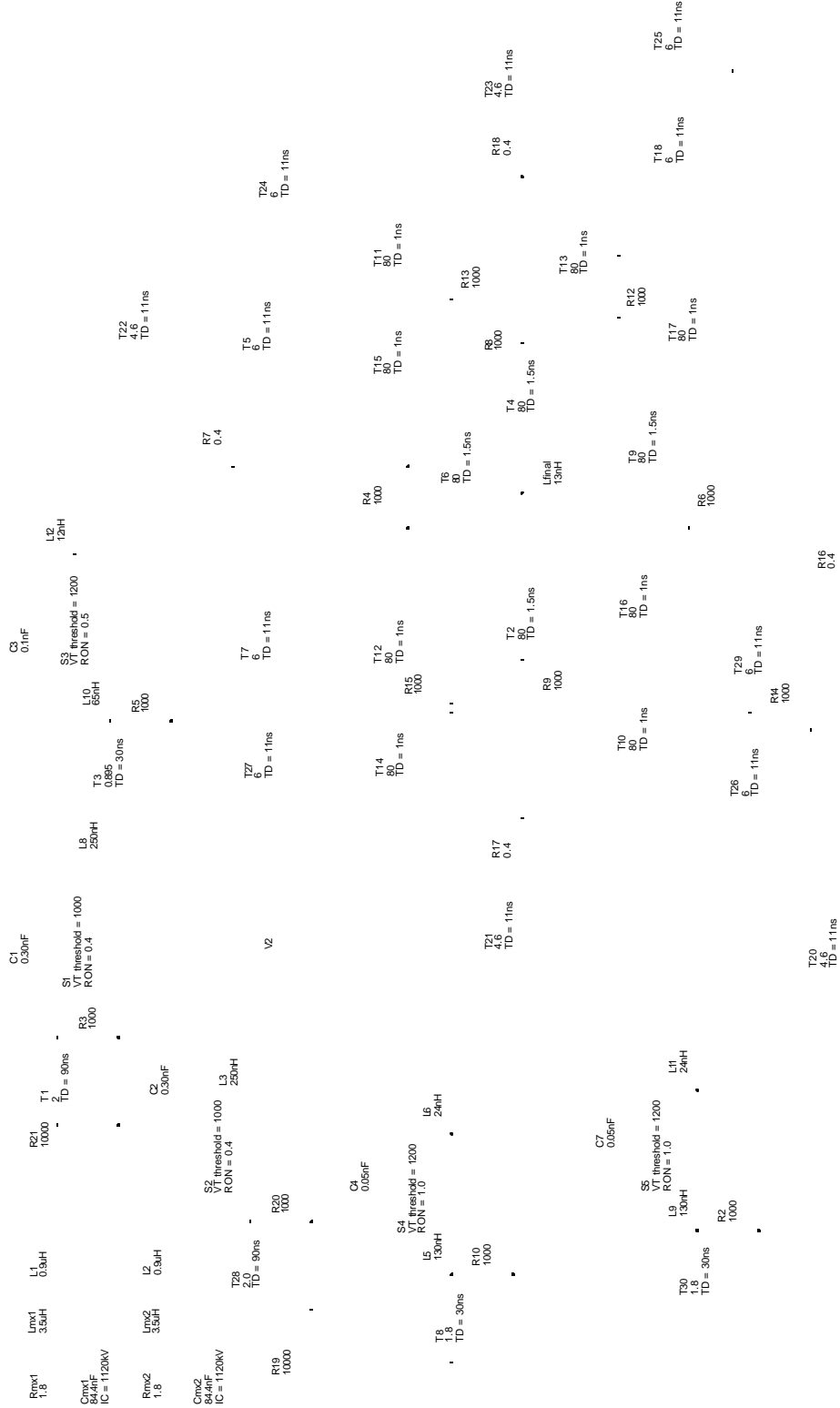


Figure 5. Spice circuit model.

Figure 6 shows the output currents achieved with different output switch closure times. These simulations use an equivalent of 70kV charge on the Marx capacitors. Figures 7 and 8 show voltage waveforms at different locations in the generator with a Z-pinch load and 70 kV Marx charge.

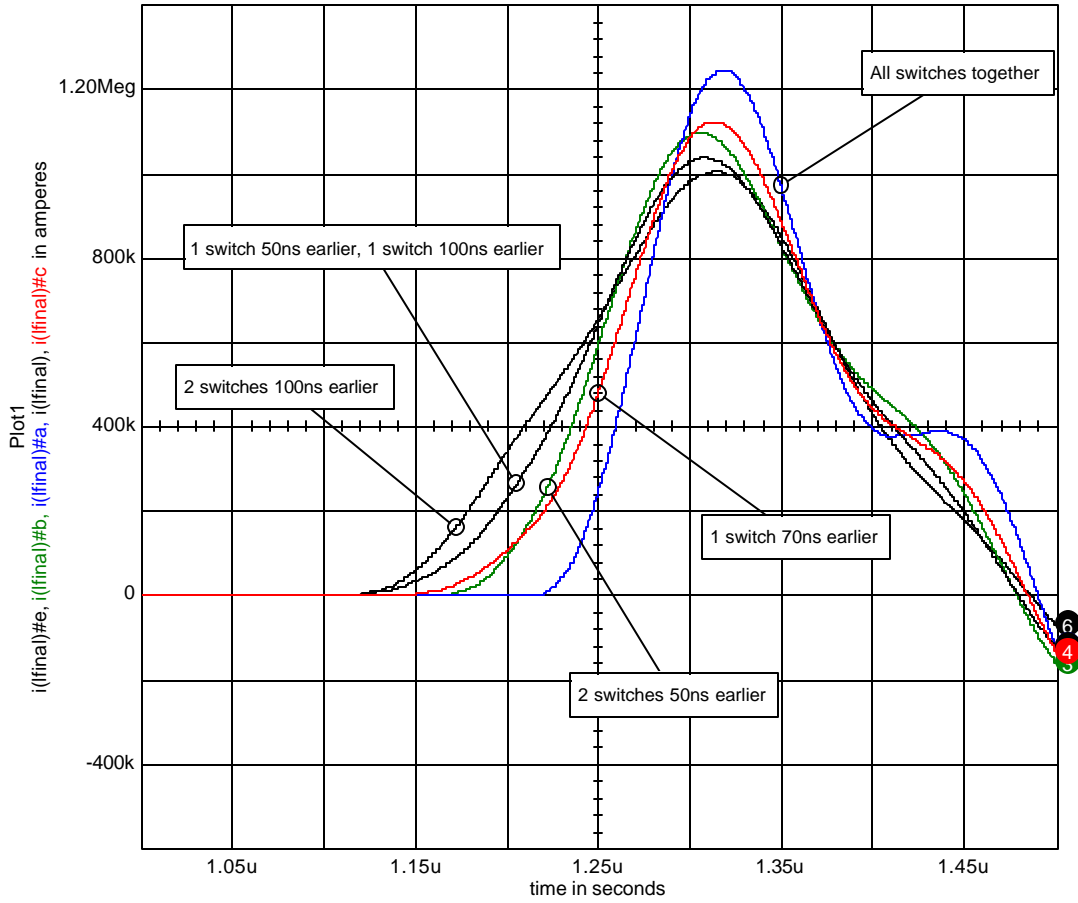


Figure 6. Load currents for different output switching times.

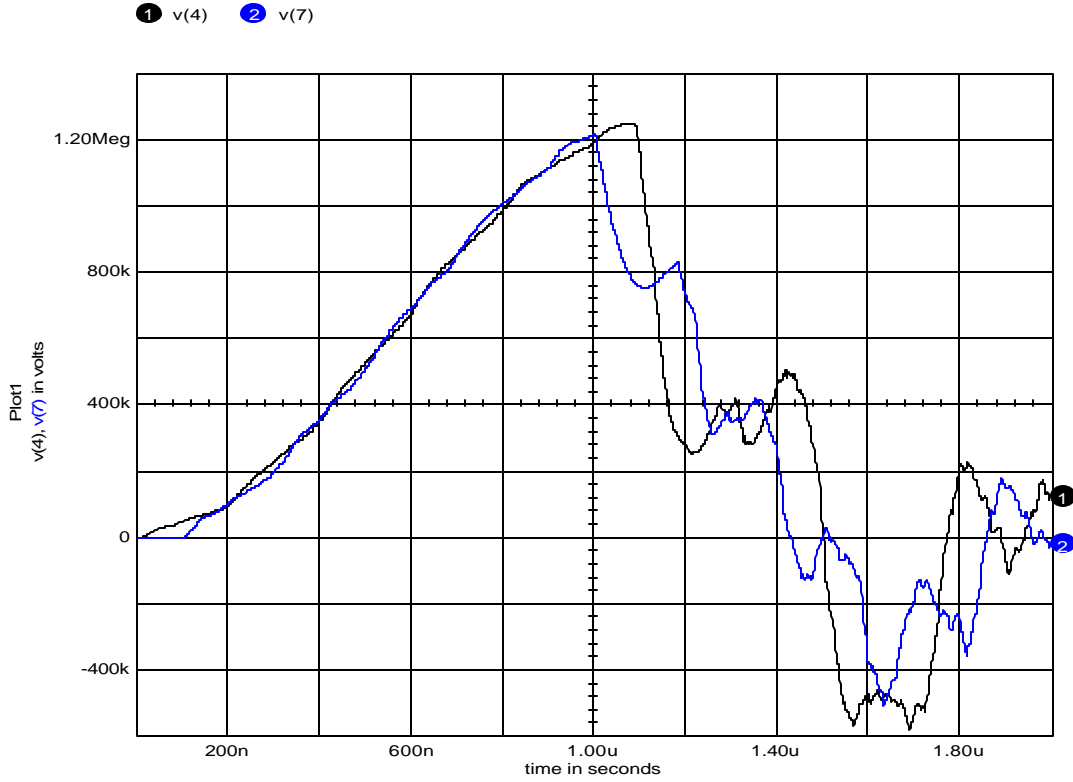


Figure 7. ISC voltages, trace 1 is at the upstream end, trace 2 is at the downstream end.

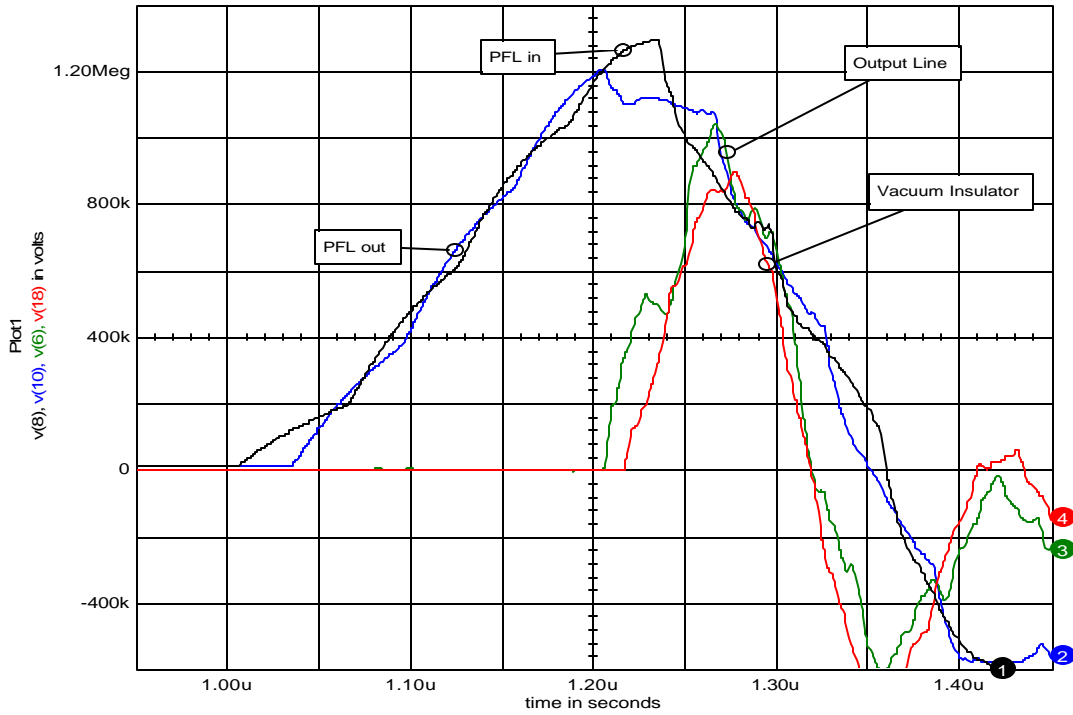


Figure 8. PFL, output line and vacuum interface voltages

Marx Generator

Each Marx generator has 8 stages with a total of 16, 1.35 μ F, 100kV capacitors. The erected capacitance is 84.4 nF at 1.12 MV for a 70 kV Marx charge. The Marx inductance is estimated to be 3.5 μ H. The connections to the ISC add an additional 0.9 μ H of inductance. The Marx is configured in 2 sections and suspended from the top of the tank in the standard Sandia fashion. Three sections are available from the old COBRA generator. The components will be obtained for a fourth section. The table below summarizes the spacing between components and the associated electric fields and breakdown strengths for a 100kV charging voltage. The electric field calculations do not take into account regions of localized field enhancement. Appropriate field shaping elements will be designed to keep the breakdown percentages below 50% where necessary.

Location	V kV	teff us	gap cm	l cm	w cm	# of locations	Ao cm ²	F+ kV/cm	E kV/cm	E/F+ %
between stages	400	0.54	7.62	63.5	27.94	6.00	10,645	294.0	52.5	17.86
between sections	1600	0.54	15.24	63.5	35.56	1.00	2,258	330.2	105.0	31.79
	1200	0.54	15.24	63.5	35.56	2.00	4,516	313.5	78.7	25.12
to floor	1600	0.54	15.24	63.5	27.94	1.00	1,774	336.3	105.0	31.22
to wall, output side	1600	0.54	15.24	63.5	35.56	1.00	2,258	330.2	105.0	31.79
	1400	0.54	15.24	63.5	35.56	2.00	4,516	313.5	91.9	29.30
to wall, input side	800	0.54	7.62	63.5	35.56	1.00	2,258	330.2	105.0	31.79
	600	0.54	7.62	63.5	35.56	2.00	4,516	313.5	78.7	25.12
support straps, mean fields	1000			30.5				180.0	32.8	18.23

The radial electric field along the 84 cm diameter plastic oil/water interface will be < 100 kV/cm.

The trigger generator for the existing COBRA accelerator will be duplicated and used to trigger the second Marx generator.

The Marx will be removed from the tank for servicing. Assembly issues involved in connecting the Marx to the interface between the Marx and ISC are still being

investigated. The Marx tanks as shown have space on either end of the Marx sections for an individual to stand. However, it may be necessary to make the tanks wider to accommodate the output connections.

A double wall tank is required for oil containment. The gross volume of each tank is approximately 2000 gallons.

Intermediate Storage Capacitor

In order to conserve floor space and take advantage of the structure needed for the tall Marx tanks, a vertically oriented flat plate intermediate storage capacitor is envisioned. One outer wall of the double wall Marx tank will be fabricated using stainless steel and will serve as one side of the ISC tank. The inner conductor will be suspended from the top of the tank. Soft copper tubing will be used to make the connections to the Marx and gas switch. A hole in the inner conductor will allow connections to Marx interface to be made from the output side of the ISC. Some parameters of each ISC are shown below.

width	height	spacing	Ao	C	V	t _{eff}	Ao	Eo	F+	Eo/F+	F-	Ei/F-
cm	cm	cm	cm ²	nF	kV	us	cm ²	kV/cm	kV/cm	%	kV/cm	%
305	152	16	101,992	45.7	1200	0.54	92,720	75.0	144.7	51.8	306.7	24.5

ISC Switch

Originally, we planned to use electrically triggered gas insulated spark gaps to discharge the ISC into the PFL's. However, it may be possible to achieve adequate control and reproducibility with self break switches, since we intend to use triggered output switches. The existing COBRA switch was operated in the self break mode at ~ 2.5 MV. We anticipate using this switch with the length of the main gap reduced and several of the following gaps removed. A second switch with the same configuration will be built.

Each switch is connected to 2 PFL's. Waveforms of the voltage at the upstream end of the switch and current through the switch are shown in Figure 9.

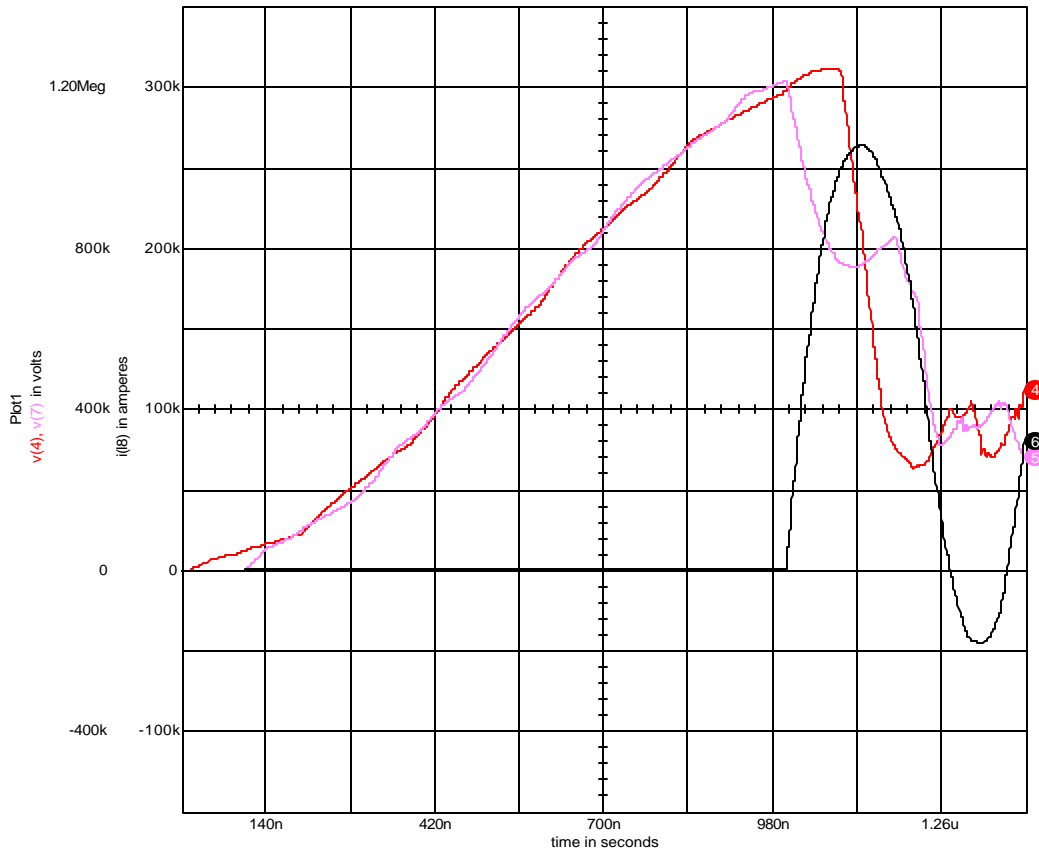


Figure 9. Voltage at the output of the ISC, and current through the switch.

Pulse Forming Line

Four, 1.8 O, 30 ns water dielectric coaxial PFL's will be used. Some parameters of each PFL are shown below.

t	l	Z	V	teff	ro/ri	ro	ri	Ao	Eo	F+	Eo/F+	Ei	F-	Ei/F-
ns	cm	ohm	kV	us		cm	cm	cm ²	kV/cm	kV/cm	%			%
PFL														
30.0	100.0	1.80	1300	0.13	1.31	36.0	27.5	22,619	134	254	52.8	175	548	32.0
PFL to Oil/Water interface														
7.0	23.3	3.90	1300	0.13	1.79	23.0	12.8	3,372	97	283	34.1	173	626	27.7

Electric field plots of the ends and elbow regions will be generated to determine the geometry required at these locations to keep the fields enhancement within prescribed limits.

Output Switch

Laser trigger gas insulated spark gaps will be used for the output switches. They will hold off 1.3 MV and conduct 220 kA. Waveforms of the voltage at the upstream end of the switch and current through the switch are shown in Figure 10. The double hump in the current pulse-shape is a result of the peaking capacitor in the adder region.

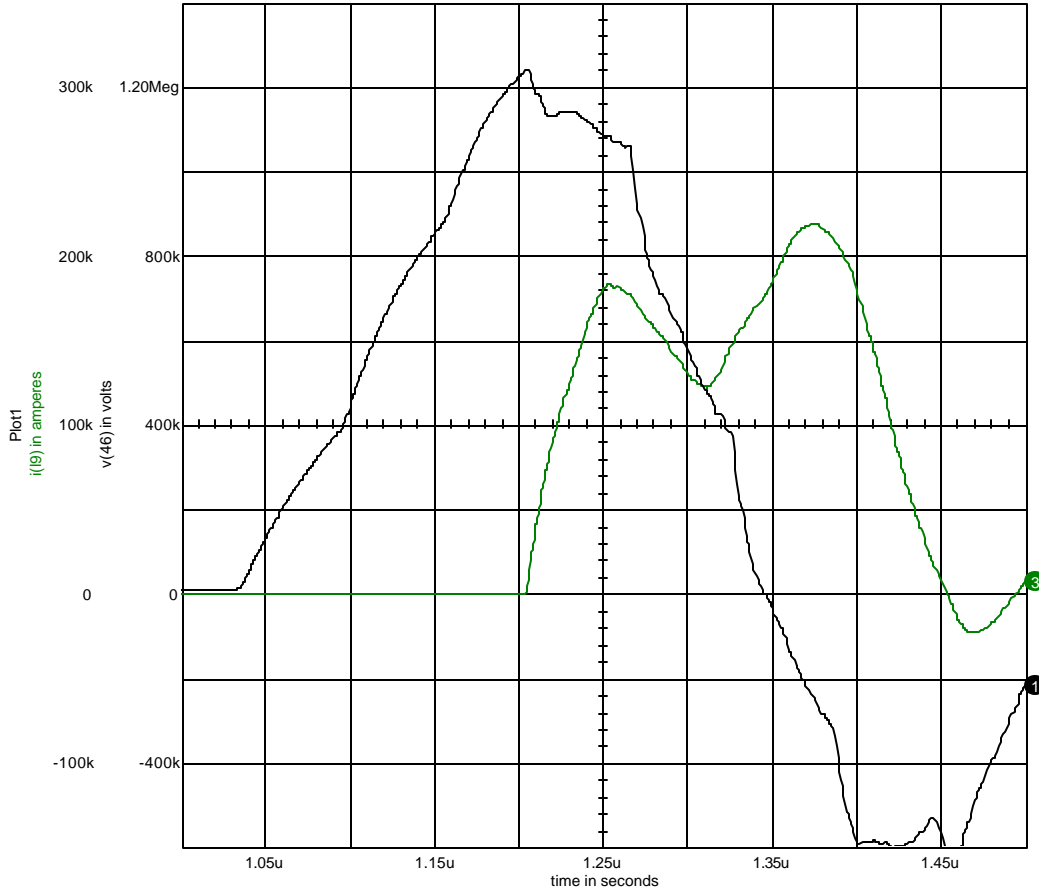


Figure 10. Voltage at the upstream end of output switch and current through the switch

The output switches are scaled-down versions of the laser-triggered Hermes III switch. A plot of the potential distribution along the switch is shown in Figure 11. At our nominal operating level, the electric field along the insulator is <80 kV/cm. The electric field in the gaps is 195 kV/cm with 25% of the voltage appearing across the triggered gap. The electric field in the region near the field shaper is at 80% of breakdown. We will likely increase the diameter of the outer cylinder slightly. We would like to keep this dimension small in order to provide better access to the bottom of the vacuum region. The detailed design of this switch is still underway.

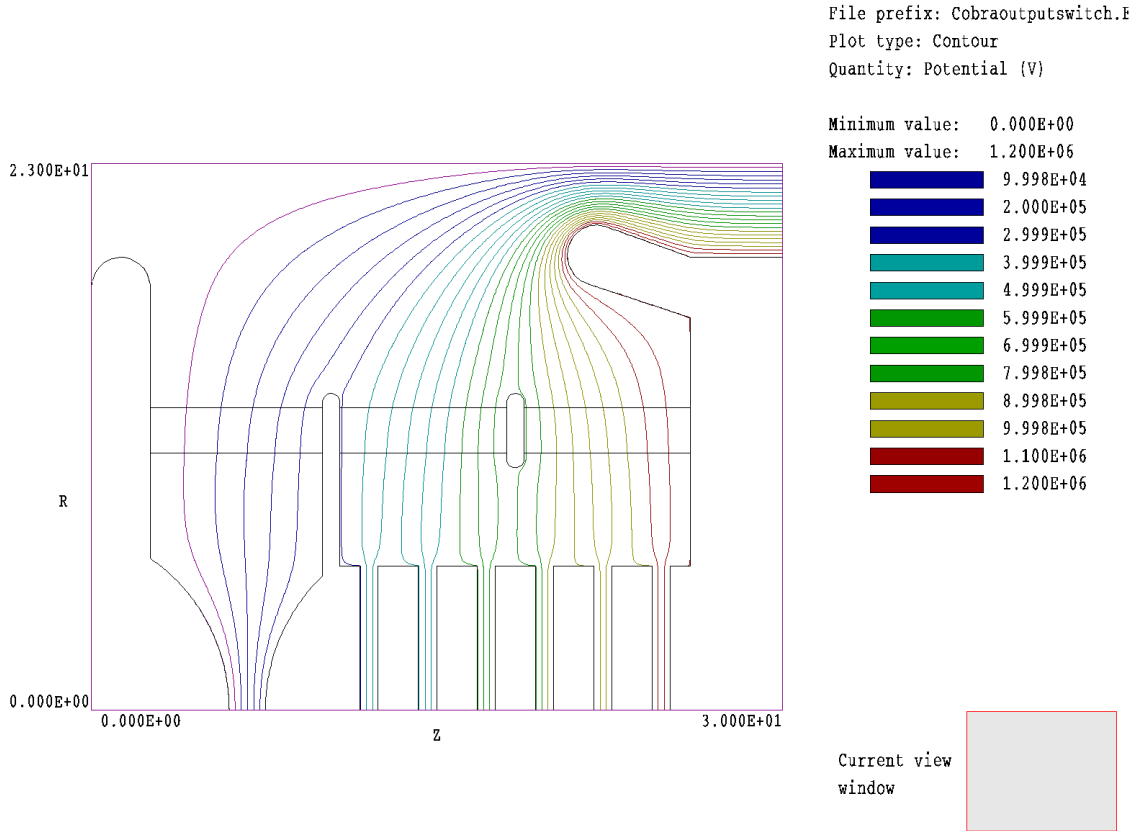


Figure 11. Potential distribution along the output switch

A frequency quadrupled Nd:YAG laser is being considered for the trigger. The optical path to the trigger gap has not been determined.

The output switches are located in oil insulated lines to minimize the shunt capacitance of the switch. Oil/water interfaces are required at both ends of the lines. The lines are tilted 15 degrees from vertical to eliminate air bubbles on the bottoms of the interfaces and also to provide better access to the bottom of the vacuum region.

Switch inductance is estimated at 130 nH. A 25% increase in this value decreases the peak load current by 4% while increasing the pulse risetime by 3 ns. The effects of increased switch inductance on load current, based on Spice circuit simulation, are shown in Figure 12.

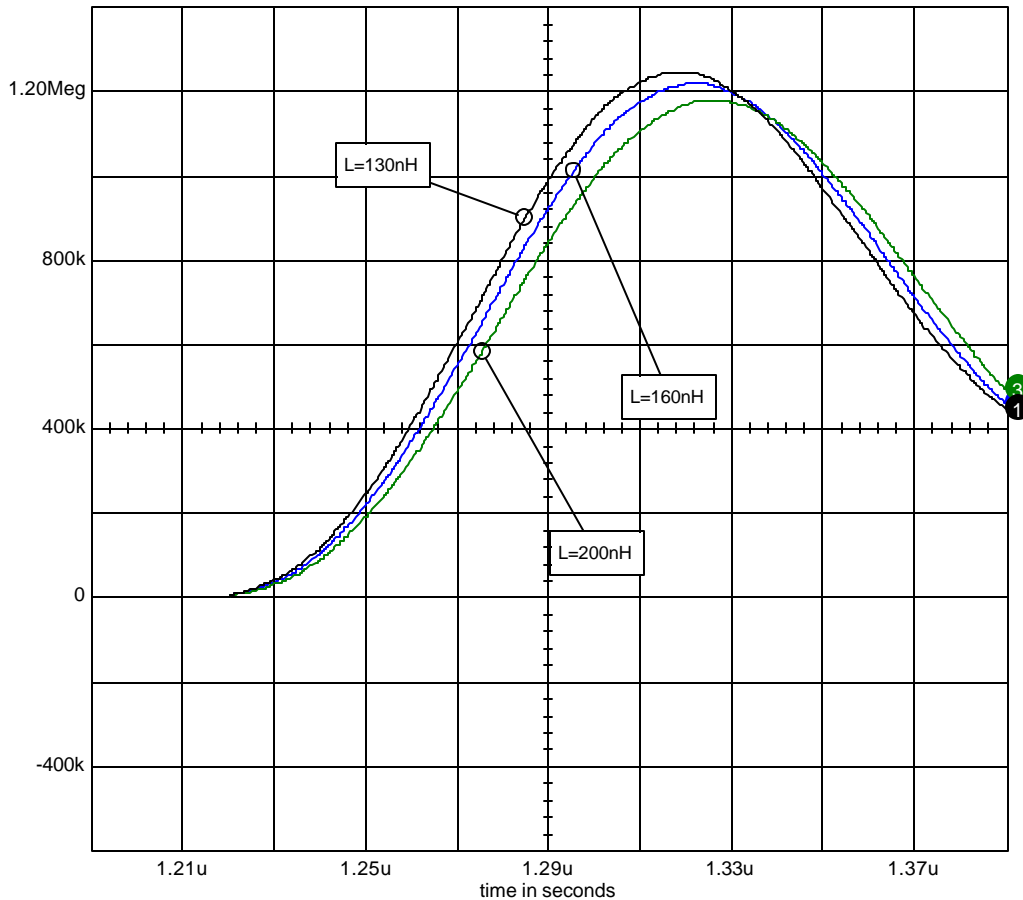


Figure 12. The effects of increased switch inductance on load current.

Adder Section

The adder section is an approximately 150 cm diameter cylinder that contains the peaking capacitor, vacuum interface, vacuum power feed and load region. A cross section view of this region is shown in Figure 13.

The outer annular region of the adder section is filled with water and acts as a 14 nF peaking capacitor. The addition of this capacitance compensates for the high inductance of the output switches. Without this capacitance, the peak load current is 20% less, and the risetime 20 ns longer. Because of the slow propagation speed in water, some of the current from the output lines flows into the vacuum region and radially around the power feed to charge the peaking capacitor.

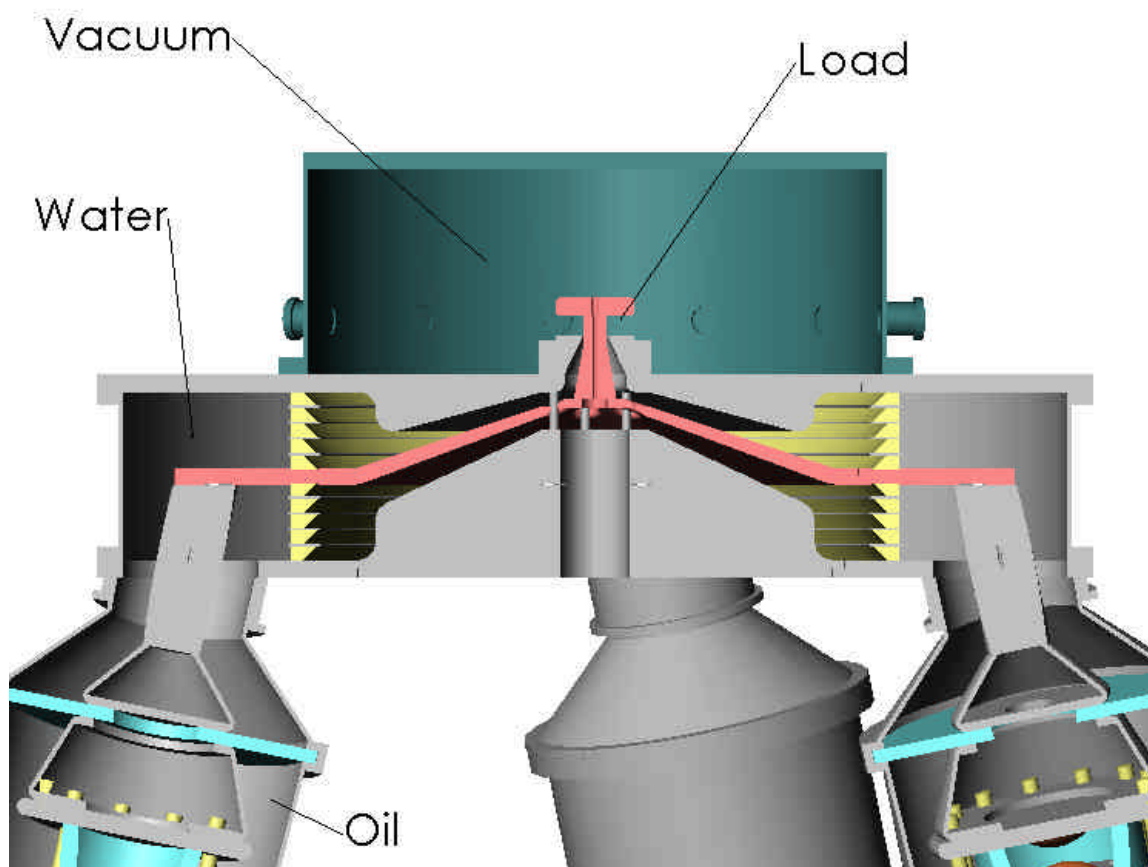


Figure 13. Adder section

A plot of the potential distribution along the water vacuum interface region is shown in Figure 14. The average electric field along the 45 degree surface of the most highly stressed vacuum insulator ring is 66 kV/cm. This electric field is about 55 % of the flashover strength of the insulator stack because the use of the peaking capacitor increases the duration the voltage is imposed across the vacuum interface. The maximum electric field along this insulator ring is 95 kV/cm. We will probably add another insulator ring to each side of the stack.

The power feed has a conical cathode feed plate sandwiched between 2 anode plates. There is a convolute at a radius of approximately 6 cm followed by a short vertical conical section. The purpose of this is to shield the vacuum interface from debris and to raise the load above the height of the interface to provide horizontal access for diagnostics. The final geometry of the vacuum power feed is still being determined. The shape shown in Figure 13 is an approximation. The power feed will be designed so that the anode and cathode cones can be removed from the top of the vacuum region to provide access to the vacuum insulators for cleaning.

This design provides access to both the top and bottom side of the load, allowing for instance, for easy propagation of a laser beam in parallel with the vertical orientation of the load for diagnostic purposes.

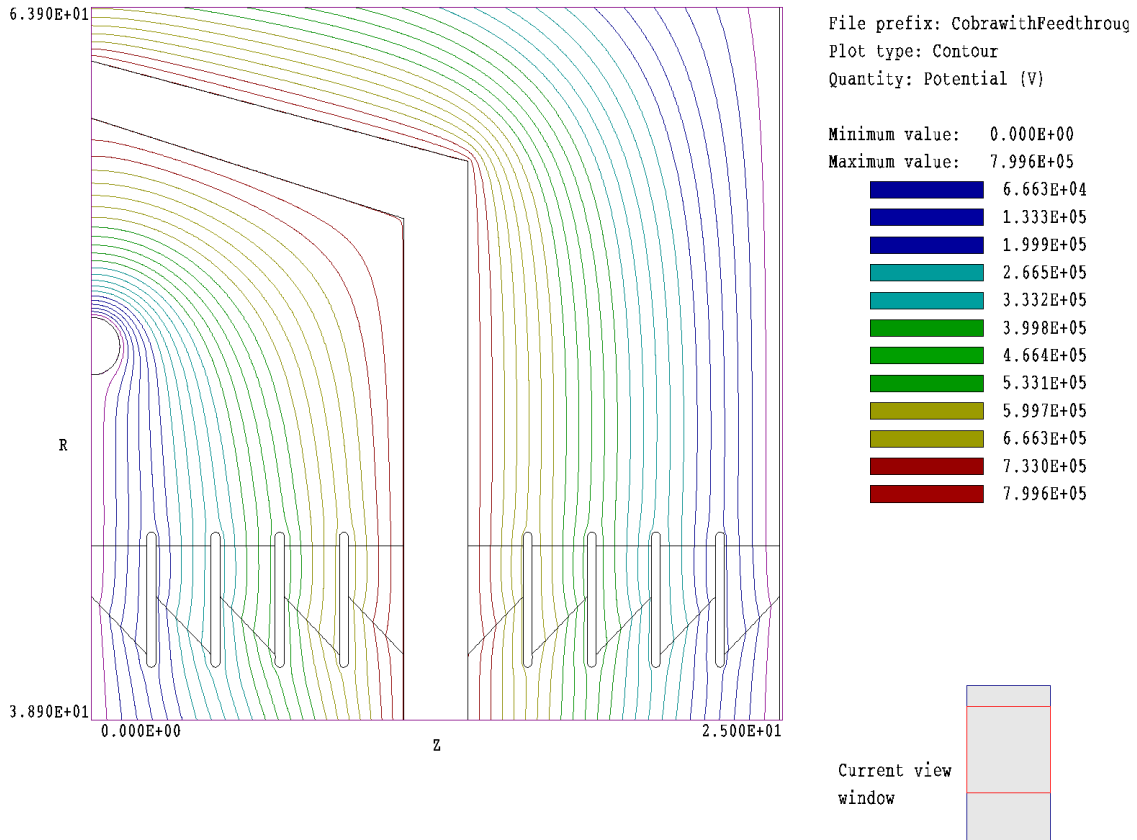


Figure 14. Potential distribution along water/vacuum interface.

Diagnostics

The Marx generators will have current and voltage monitors. D-dot voltage monitors will be used on the ISC's and PFL's. B-dots will be used to monitor the current at different azimuthal and radial locations along the power feed.

Summary

This document describes the overall baseline design. Many of the details and several key issues such as the optical path for triggering the output switches are still under development.